Mapping Sawgrass Densities in the Florida Everglades Using Spectral Data and Digital Multispectral Video

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ABSTRACT

Changes in vegetation distribution patterns within the Florida Everglades have been documented by many researchers. Competition between native and invasive species are mainly due to altered hydrologic regimes and nutrient fluxes fostered by agriculture and urbanization. The eutrophication of many areas in the Everglades is blamed for the success of *Typha spp.* (L.) where it outcompetes the native *C. jamaicense* (C.). Plant composition and density have been shown to affect surface flow, prolonging retention times for nutrients. Hydrologically, the sheet flow in the Everglades is interrupted by plant material occupying a shallow water column. Presently, efforts are being made to develop vegetation resistance-to-flow models that will predict flow rates based upon vegetation density. This paper describes the derivation of plant density from digital multispectral videography (DMSV) for the purpose of large-scale vegetation modeling. Seasonal sampling is being conducted at quadrats established in the Everglades representing different densities of sawgrass. Non-imaging spectral measurements are also being collected to characterize plant communities as well as calibrate imagery data sets. Early results show biomass correlates with near IR imagery reflectance ($r = 0.72$). However, stronger correlations ($r = 0.77$) between biomass and reflectance occurred for sampling periods when the water level was at its lowest. Furthermore, change analysis between wet and dry season images showed a >20 percent difference in vegetation available to the DMSV field-of-view. These results indicate that characterization of vegetation density is more effective at lower water levels.

INTRODUCTION

Before agricultural and urban development impacts occurred in the late 1800's, South Florida hydrology followed the"KLOE" model, or Kissimee-Lake Okeechobee-Everglades watershed (Lodge, 1994). During the rainy season, water from the Kissimee River (including Taylor Creek, Fisheating Creek, and Nubbin Slough) entered Lake Okeechobee. With no outlet for drainage, rising water in the lake spilled south over the flat topography of the region and flowed across the Everglades expanse bringing freshwater into the marsh (Parker, 1984).

The pre-development flow in the Everglades maintained a large, wet prairie and sawgrass marsh ecosystem. These systems were dominated by *C. jamaicense* (C.), or sawgrass. Sawgrass is a tall (> 3 m), perennial sedge in the family Cyperacea. The plant grows in clumps similar to tussocks and consists of large, scale-like leaves that are long and tapered. The leaves possess short saw-toothed margins that give the plant its name. Sawgrass' color ranges from olive green during the growing season (wet season) to purple-gray (in senescence) during the dry season (Tiner, 1993).

In the last one-hundred years, South Florida's natural history has been dramatically altered by man's influence. Three agencies, the Central and South Florida Project (C & SF Project), the South Florida Water Management District (SFWMD), and the U.S. Army Corps of Engineers have been responsible for undertaking several large-scale flood control projects. South of Lake Okeechobee, the construction of flood control structures to divert water for farming and urban uses along the eastern 'Gold Coast' region has had a detrimental effect on the Everglades ecosystem (Light and Dineen, 1994). The combined impact from these projects has affected almost 80 percent of the Everglades by direct and indirect hydrologic modification (Lodge, 1994).

Conclusive research has identified some specific impacts due to development and hydrologic re-engineering of the Everglades ecosystem. Among these impacts, the alteration of nutrient (N and P) budgets and an overall shift in marsh biogeochemistry from nutrient poor to nutrient rich has caused changes in vegetation species composition and distribution patterns (Browder et al., 1994 and Davis et al., 1994). Evidence for these changes and the strong desire to maintain and preserve the ecosystem have been the driving force behind the multi-agency South Florida Ecosystem Restoration Program. A primary goal of this program is to re-establish the hydrologic integrity of the Everglades that has been lost for almost a century through developmental and flood control activities (Desmond, 1995).

Because the movement of water through the Everglades is largely by sheet flow, vegetation figures prominently in any hydrologic modeling scheme. As Lee (1996) points out, restoration and management of the Everglades requires understanding and manipulating the amount and timing of water flowing throughout the ecosystem. The timing of water movement is critical since the transport and fate of nutrients is governed by how fast water can move through

the system. With sheet flows, vegetation composition plays a critical part in determining patterns of flow and retention times for water in the Everglades.

As part of the restoration program, efforts are being made to develop vegetation resistance-to-flow models. These models are being designed to predict flow rates through the Everglades and will rely heavily upon the density of vegetation as a variable. To make vegetation resistance-to-flow a practical, large-scale method for modeling surface flow characteristics, remote sensing is being applied to derive vegetation resistance as a function of plant density. To accomplish this, plant sampling, spectral reflectance measurements, and multipectral imagery are being collected on sawgrass communities at various sites located within the Everglades.

METHODS

Currently, two sites are being studied that represent different densities of sawgrass (Figure 1). These sites are the first of a planned consortium of sites located throughout the Everglades. The first site, P33, is located within Everglades National Park and represents a site having sparse amounts of sawgrass (approximately 25-200 gdw/m^2) and sizeable areas of open water. The sampling site also has large amounts of periphyton; a floating algal form composed of cyanobacteria or green algae that precipitates calcium carbonate ($CaCO_3$). The second site, NESRS3, is located in Water Conservation Area 3 (WCA3). NESRS3 represents a site having a high density of sawgrass (200-600 gdw/m^2) and very little periphyton within the sampling area.

Vegetation Sampling

Vegetation sampling is conducted within a 60 m-by-60 m square quadrat divided into 15 m subsections. This provides up to 16 sampling cells within the quadrat (see Figure 1). Both destructive and non-destructive methods are used to characterize the sawgrass within a sample. Destructive methods involve cutting a 1 m section of sawgrass (within a $1m^2$ area) divided into 10 cm sections from the base of the plant where it is anchored into the peat substrate to just above the water surface. These samples are dried and weighed to provide living and dead biomass measurements for a $1m^3$ volume through the water column. Non-destructive sampling involves the estimate of coverage within a square meter sample using a template (Carter and Rybicki, 1996).

Field Spectral Measurements

Coincident with vegetation sampling, the collection of spectral reflectance measurements was made by using an ASD PS II spectroradiometer. These data are being used to characterize reflectance and absorption spectra for the different densities of sawgrass occurring within each sampling site. The PSII has a resolution of 3 nm and records a continuous spectrum from 350 to 1100

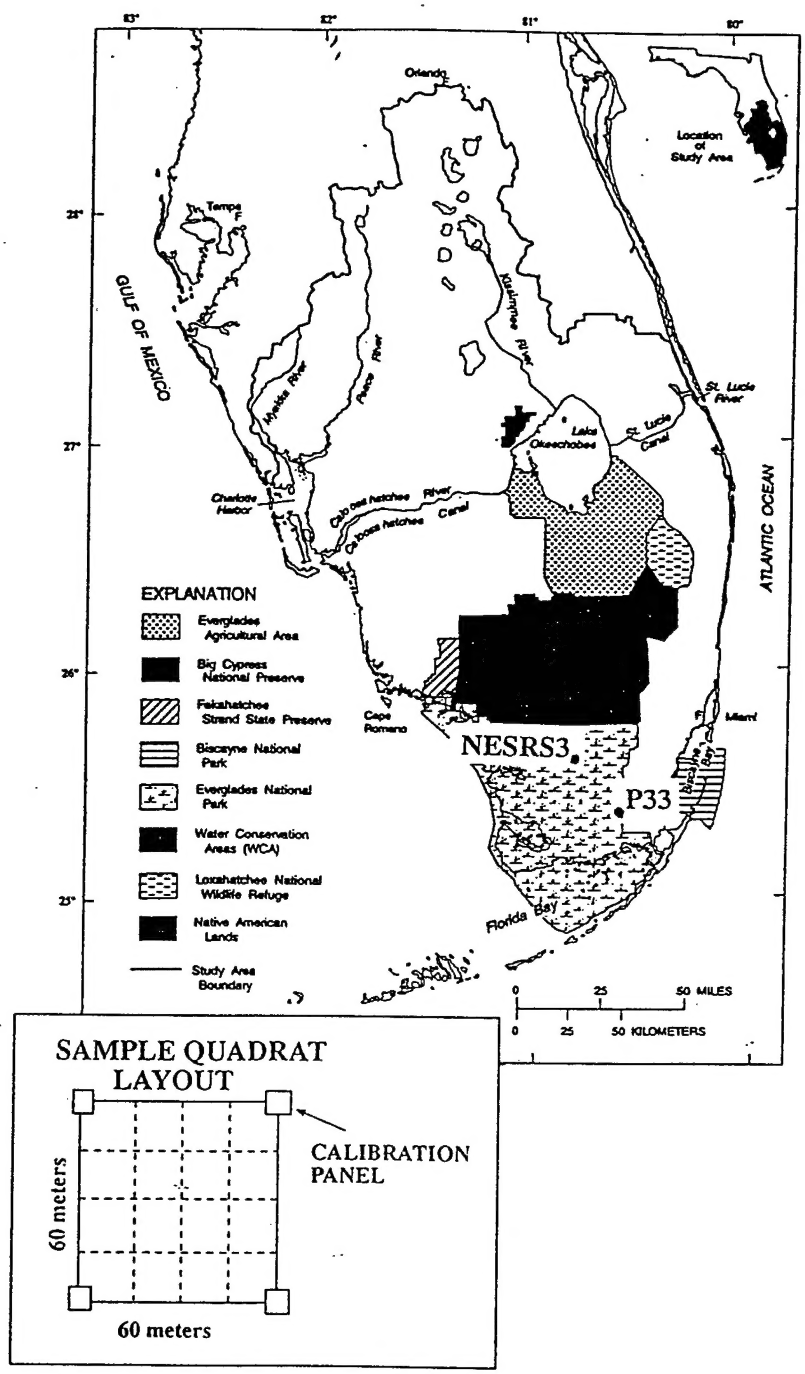


Figure 1. Location map and quadrat sampling diagram for project sites in South Florida.

nm. This region contains both reflectance and absorption features unique to the vegetation and also represents the spectral bands available to the DMSV detectors. The radiometer was calibrated using a Labsphere Spectralon (halon) reflectance standard following the procedures outlined by Satterwhite and Henley (1991). Field spectra for sawgrass canopies was measured in full sunlight at a distance of 1 m with an 18 degree field-of view (fov) collimator. All measurements were collected during the same time of day the multispectral imagery was collected.

Multispectral Imagery Data

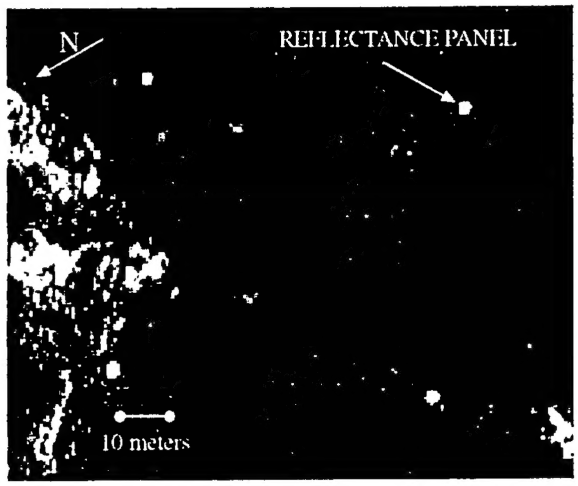
Spectral relationships recorded using the field radiometer are being applied in the image domain by using high-resolution, calibrated digital multispectral video (DMSV). The DMSV is a four channel, multispectral imaging system capable of recording continuous visible and near infrared imagery along a line-of-flight. The DMSV incorporates 24 mm focal length lenses and CCD arrays of 740-by-578 pixels within a four-camera optical head. The system acquires imagery of high spatial (.5 m/pixel ground sample distance) and high spectral resolution (bands < 25 nm wide) that, when integrated with the field data, allow detailed spectral analysis to be performed.

Narrow band imagery is being collected using 25 nm wide bandpass interference filters to control four visible to near IR spectral wavebands centered at 450 nm, 550 nm, 650 nm, and 770 nm. Missions are flown at 1,650 m producing a scale of about 1:12,000. This provides multispectral frame imagery having resolutions of .5 m/pixel ground sample distance. Prior to each mission, ground calibration targets are placed on the boundaries of the sample areas (Figure 2). The targets are surveyed using a global positioning system and provide radiometric (reflectance) calibration for the final imagery data. Post processing of the data involves corrections for bidirectional reflectance (BRDF), registration, and interlacing (Anderson, et al. 1996 and Fischer, 1996).

ANALYSIS

Figure 3 presents field spectra for sawgrass collected from the P33 (sparse) sampling site and the NESRS3 (dense) sampling site during the 1996 growing season. As illustrated by these measurements, changes in the visible region (450 nm to 700 nm) are small. In fact, a < 5 percent reflectance between dense and sparse sawgrass exists, making detection and separation using visible spectral bands difficult. A greater and more detectable difference occurs at longer wavelengths in the near IR starting around 750 nm. In this region, a 20 percent difference in the spectral separability of sparse and dense sawgrass occurs. This spectral region is predominantly affected by plant tissue constituents.

Imagery spectral reflectance using the 770 nm band demonstrates similar trends between dense and sparse sawgrass. Regression analysis resulted in correlations between regularly sampled imagery pixels (3-by-3 matrix) within



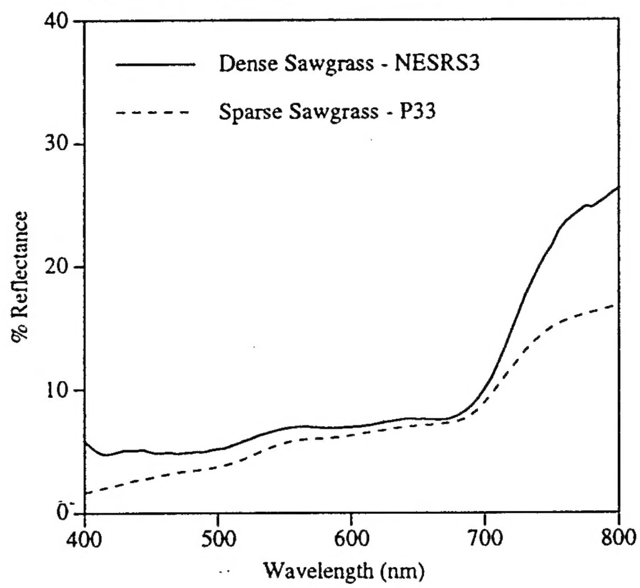


Figure 2 (TOP). DMSV band 2 (550 nm) of P33 site.

Figure 3 (BOTTOM). Field spectra for dense and sparse sawgrass.

the 15 m sub-cells of each quadrat and field biomass measurements. Figure 4 presents regressions for combined biomass and imagery reflectance obtained at each site during the wet (April) and dry (August) seasons. August relationships were found to be stronger ($r = 0.77$) due to more vegetation available to the fov of the DMSV instrument. At this time, water levels were approximately .5 m deep at each site. This is in contrast to April where water levels were >1 m.

Change analysis was performed on April and August images to evaluate the abundance of detectable plant material between the wet and dry season. Prior to change analysis, a simple normalized vegetation index (NDVI) was created for April and August scenes using DMSV bands 3 (650 nm) and 4 (770 nm). This permitted NDVI images to be generated representing only the vegetation abundance within each quadrat. Following methods described by Tucker (1979) the following equation was applied:

$$\text{NDVI} = 770\text{ nm} - 650\text{ nm} / 770\text{ nm} + 650\text{ nm} \qquad (1)$$

Using a change detection algorithm described by Jensen (1986) (Equation 2), co-registered scenes showed a 60 percent difference between the wet and dry season at the P33 site (Figure 5). The analysis also showed a 20 percent difference between wet and dry season vegetation for the NESRS3 site (Figure 6). This difference shows a greater amount of sawgrass available to the fov of the DSMV sensor during the dry season when water levels were at their lowest.

$$\Delta_{IMAGE} = IMAGE_1 - IMAGE_2 + 255 \qquad (2)$$

DISCUSSION

Field spectral measurements collected on dense and sparse sawgrass canopies established that detectable differences occur between these vegetation densities in the near IR. The differences were due to these measurements being greatly influenced by the amount of biomass available to the field-of-view (fov) of the radiometer . In the case of the dense sawgrass, plant constituents easily filled the fov, where sparse sawgrass did not. In addition, sparse sawgrass allowed more water component to contribute to the overall spectra, thus reducing the vegetation spectral signature.

Regression analysis demonstrated correlations between biomass densities and imagery spectral reflectance centered at 770 nm. However, a stronger correlation ($r = 0.77$) occurred for the August data. During this sampling period the water levels were low (<.5 m) and more vegetation was available to the fov of the DMSV. The DMSV imagery shows that sawgrass densities can be derived using remotely sensed imagery; however, these data also show that results can vary greatly with the level of water present in the marsh. To

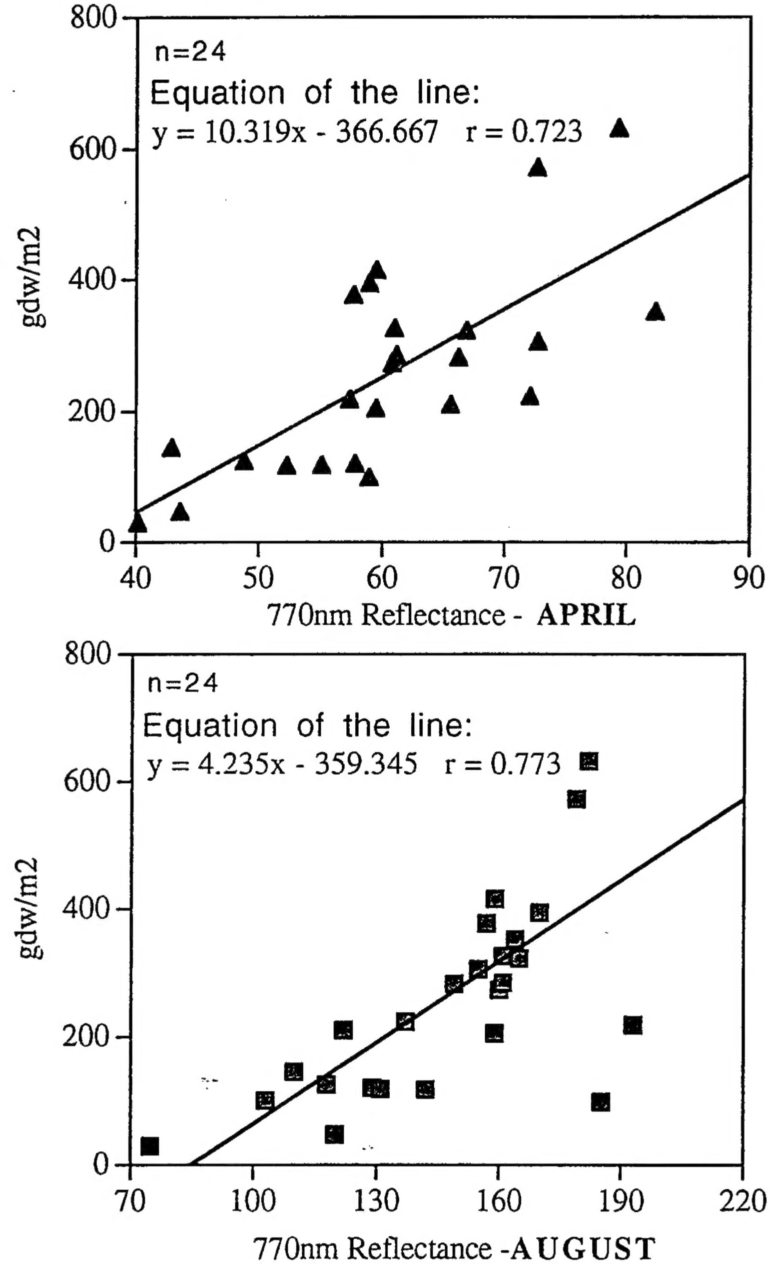


Figure 4. Linear regression models for imagery reflectance and biomass at the P33 and NESRS3 sampling sites.

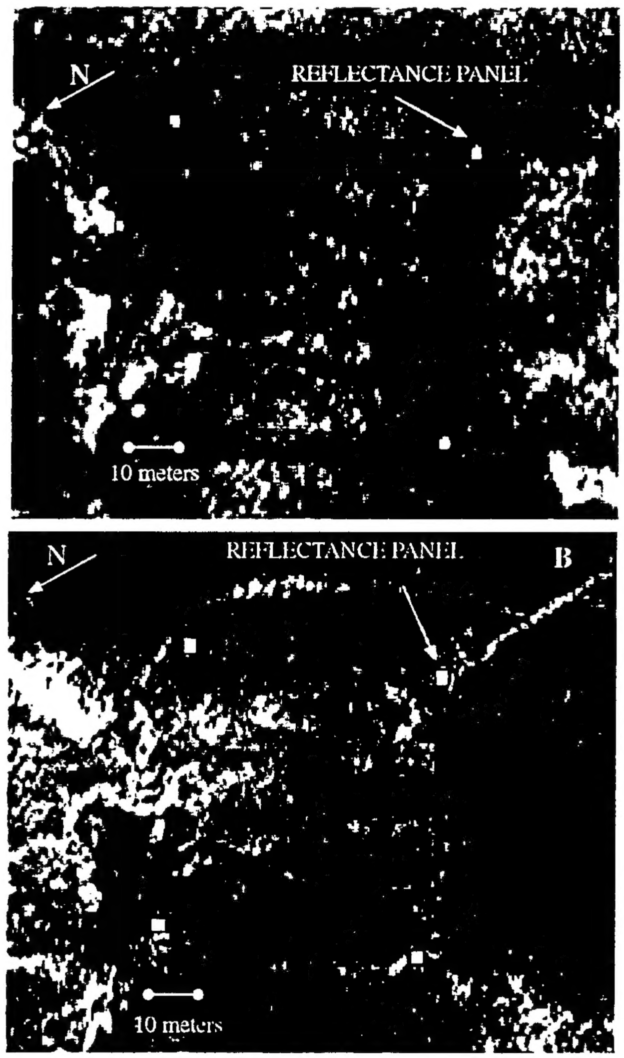


Figure 5. Image A presents an example of DMSV band 4 (770 nm) data showing August P33 quadrat. Image B shows areas of significant change between August and April in black.

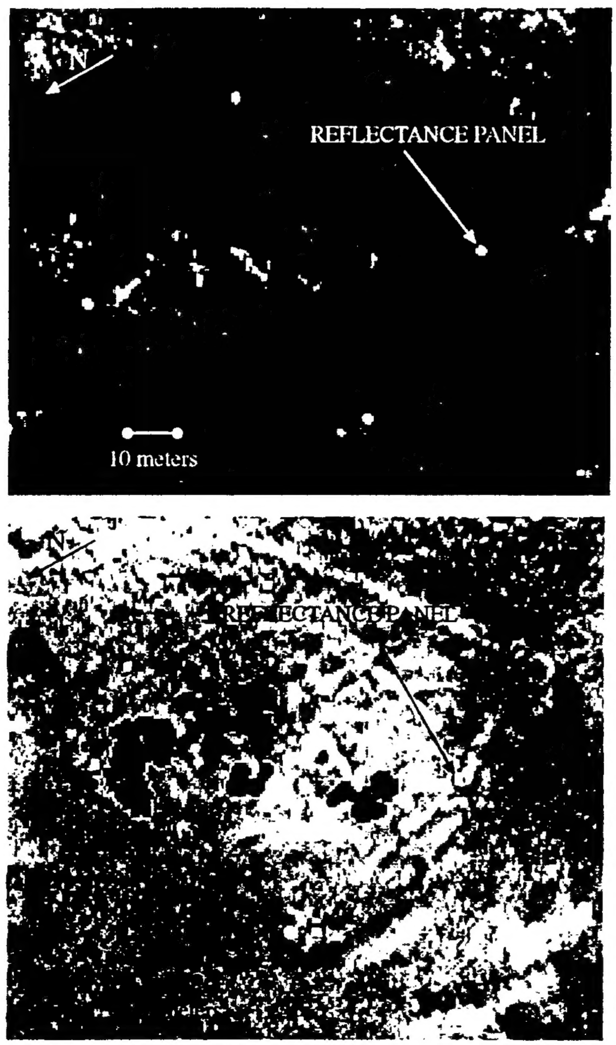


Figure 6. Image A presents an example of DMSV band 4 (770 nm) data showing August NESRS3 quadrat. Image B shows areas of significant change between August and April in black.

overcome this, a seasonal remote sensing strategy is the key for accurate characterization of vegetation densities in the Everglades. This study indicates that if densities derived from remote sensing are used as variables to vegetation resistance-to-flow models, data acquired during the dry season will provide a more realistic representation of the vegetation community at large.

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